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Feasibility of Using Plastic Pipe for Ethanol Gathering

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System Design for Pipeline Comparison

An ethanol pipeline system was designed around a flat theoretical corn producing region. This pipeline was designed to transport ethanol from several production plants to a class 1 railroad. Taking this into consideration, along with comments from the steering committee, the rough theoretical system was designed as shown in Figure 1.

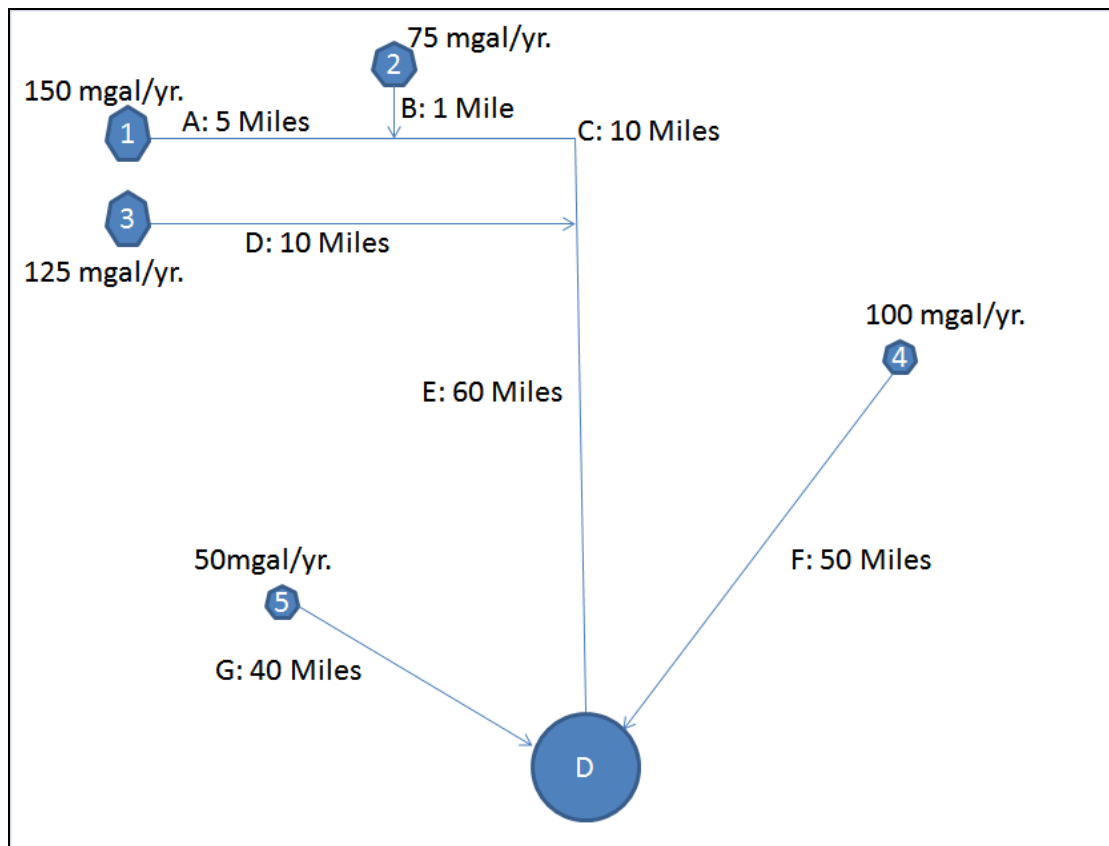


Figure 1: Theoretical piping system used for cost comparisons.

The theoretical ethanol piping system has five (5) ethanol producing plants of various capacities. Two of the plants, numbers 4 and 5, deliver directly to the final destination D. Three other plants feed to a central line which then feeds to the distribution point D. The capacity of each segment of pipe (labeled A through G) is controlled by facilities that are feeding the line and their production capacity. The different pipe products were considered for the piping system by using the pipes' specification to determine, size, flow rates, and other factors. The requirements for each pipeline section are contained in Table 1. The different capacities and lengths of the sections will allow for comparison of the different needs of an ethanol piping system.

Table 1: List of the section lengths and required capacity

Section	Pipe Length (miles)	Capacity (million gallon/year)
A	5	150
B	1	75
C	13	225
D	10	125
E	60	350
F	50	100
G	40	50

Flow and Pressure Calculations

The calculations to design the pipeline system were based on the *US Army Corps of Engineers – Liquid Process Piping, Engineer Manual* and data supplied by the pipe manufactures. To perform the calculations to determine the pressure drop across the pipe system and the flow capacity of the pipe these assumptions were made:

- No elevation changes: The calculations do not consider any increase in pressure required to flow a liquid up an elevation change, nor does it consider the reduced pumping needs if flowing down an elevation change. This is a reasonable assumption for the area of the United States that would be utilized for ethanol production.
- Turbulent flow: Initial calculations show that expected flow is turbulent, and is not near the transition region to laminar flow.
- Pipe joints do not cause a pressure drop: Pipe joints are necessary to create a pipeline of sufficient length. These joints will vary depending on pipe material. It is assumed that these joints do not contribute any additional resistance to the ethanol flow. This is often assumed to be the case in butt fusions joints in thermoplastic water systems.
- A minimum pressure of 20 psig was maintained on the system: To account for minor fluctuations and possible needs at a final destination or pumping stations the minimum pressure the system was designed at 20 psig. This number could be adjusted as needed.
- No water hammer affects were considered: The sudden change in pressure in a liquid system, such as a complete shut off, or pressure variance from pumping stations, will cause a pressure wave to propagate through the liquid. The pressure wave temporarily increases the local pressure and, depending on the frequency of events, will cause cyclic loading. These issues are minimal for thermoplastic systems as they tolerate the effect well but could affect the composite pipes. Additionally, a piping system can be designed to minimize the causes of the water hammer effect.
- Crossings have negligible effect: The calculation do account for the same number of crossings for each system by adding a length of pipe equivalent to the expected pressure drop at the crossing to the overall system. However, at a lower number of crossings, these accounts for less than 1% of the total system length. Thus for this comparison, crossings were neglected, and further investigations into pressure losses due to crossings were not warranted.

- Valves were not considered: In any pipeline of this size there would be valves and flow control systems necessary to maintain proper flow and allow for maintenance. These were not considered during this evaluation as they would have had a limited effect on the system, and would not affect the choice of which pipe material to use.
- Pumping stations: Pumping stations required to maintain adequate pressure were considered based on the pressure drop calculated from piping losses, and the lower required pressure. The variation of pumping stations accounted for in this study was determined by analyzing the added pressure drop per foot of piping related to each material.

The calculations took into account the properties of ethanol, shown in Table 2. These properties combined with the properties of the pipe material were utilized in determining the flow rates and pressure drops for a given section of pipe in the above benchmark system.

Table 2: Ethanol properties used in calculations

Property	Value	Units
Density	49.3	Pound mass per cubic feet
Viscosity	0.0000736	Pound mass per foot*second
Kinematic Viscosity	0.00001636	Feet squared per second
Specific Gravity	0.789	
Bulk Modulus	130824	psi

The flow calculation uses the volume flow through the section along with the pipe diameter to determine the fluid flow rate. As a rule of thumb this flow rate is recommended to not exceed 13 feet per second. The flow rate, pipe size, and ethanol properties were then used to calculate the Reynolds number. The friction factor for the pipe is then calculated using these values and the assumed pipe constants in an iterative fashion after using an initial estimate. The friction factor in conjunction with the flow rate, pipe size, and “Re” number can be used then to calculate the pressure loss for a given length of pipe. This value is then used to determine the total pressure loss over an entire pipe section. Full details of the methodology of these calculations are contained in the *US Army Corps of Engineers – Liquid Process Piping, Engineer Manual*.

The total pressure loss over a pipe section is the minimum pressure required to pump the specified amount of ethanol over the distance of the section, with the specified end pressure. In some cases this pressure can be immense and unrealistic for non-metallic pipes to maintain integrity at those pressures. This can be designed around by introducing larger pipe diameters, which would increase the fluid flow area, and thus reduce the pressure loss over a section of pipe. If the pipe section cannot withstand the pressure required to transport the ethanol pumping stations are necessary to boost pressures back to design pressure. Essentially this allows the pipeline to be operated at lower pressures, by boosting the pressure often before it falls below design pressure.

Materials Chosen to Evaluate

This base system was then designed for use with the various identified non-metallic piping systems. This allowed for the evaluation of the feasibility of utilizing the pipe materials for

ethanol transport. The design of this example piping system assumes the pipe will maintain its current pressure rating (HDB) and not fail prematurely due to the presence of ethanol. This assumption was made for this analysis and would need further testing to verify.

The materials chosen for this evaluation were:

1. High density polyethylene: HDPE 100 materials were considered for this effort. This is a common piping material and has wide acceptance in the natural gas industry. HDPE will act as a baseline for considering a non-metallic piping system.
2. Polyamide: PA materials are coming into wider use in the delivery of natural gas and have higher pressure carrying capacity than PE materials of the same SDR.
3. Epoxy Resin pipe (Red Thread II): These materials have been used extensively in gasoline stations, gathering systems, and other chemical environments. The epoxy pipe has a higher pressure rating than that of thermoplastics.
4. Composite pipe: Composite pipe is becoming more utilized and considered for different applications as it can maintain high strength along with the chemical resistance of lower strength polymers. The composite pipes have the highest pressure rating of the pipe materials considered.

These materials have been used in construction of pipelines and the tools and experience exist to install these materials. There also exists a full complement of fittings and transitions for these pipeline products. This would allow for junctions with other pipeline assets and also for connections to flow control equipment.

Pipeline Feasibility

General trends

The high flow requirements for section E of the pipeline led to the use of larger diameter pipes. Larger pipe diameters have larger cross sectional areas for fluid flow and therefore can maintain high flow volumes without increasing the pressure requirements over desired values. Additionally in the pipe feasibility investigation focus was given to minimizing the required number of pumping stations, due to the expected cost of these stations. The goal was to have little to no pumping stations for the majority of the length of the pipeline. The roughness factor of the pipe material used was supplied by the manufacturers, but an actual experiment would be the most reliable method for determining the pressure loss over a given section of pipe. However, this may not prove that critical as the overall pressure loss of the pipeline was not significantly affected by changes in the roughness factor of the pipe. An increase by two orders of magnitude of the roughness factor lead to an increase of only 5 psig. This can be accounted for by the turbulent flow of the ethanol within the larger pipe diameters resulting in less contact between the ethanol and pipe wall than in smaller diameter pipes. This noted, the manufacture supplied roughness was found to be sufficient for this feasibility study.

High Density Polyethylene

HDPE has the lowest pressure capacity of all the pipe materials considered but has been used extensively in both natural gas and water applications. Due to the extensive use of this material there are many fittings available for the transition between lines, as well as to create appropriate joints. PE pipe is available in a variety of OD sizes from ½ inches to greater than 12 inches. The pipe sizes and additional information of the HDPE pipes considered is located in Table 3. For diameters 6 inches and below PE is available in coil form. Using pipe in coil for could prove helpful, as it would drastically reduce the number of joining procedures necessary. The HDPE pipe material was considered to have a maximum pressure capacity of 125 psig for all pipe sizes since each pipe size has the same dimensional ratio of diameter to wall thickness. Table 4 contains the results from the pipeline analysis when using HDPE as the pipe material.

Table 3: HDPE pipe sizes, length, and pressure table

Nominal Pipe size (in.)	Inner Diameter (in.)	Segment length (ft)	Pressure Capacity (psig)
2	1.917	1500	125
4	4.091	1500	125
6	6.023	500	125
8	7.841	50	125
12	11.591	50	125

Table 4: HDPE example pipeline results

Section	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psi)	Number of Compressors
A	6	3.21	500	53	67	0
B	4	3.48	1500	4	25	0
C	8	2.84	50	1373	102	0
D	6	2.68	500	106	96	0
E	12	2.02	50	6336	159	1
F	8	1.26	50	5280	91	0
G	6	1.07	500	423	75	0
TOTAL				13575		1

Polyamide

Polyamide (PA) pipe materials are becoming more common in the natural gas industry and have been used extensively in gasoline pumping stations. Due to the extensive use of these materials, fittings and transitions are available in a wide variety of sizes. PA pipe is available in the sizes and configuration as PE as shown in Table 5. The PA pipe material is considered to have a maximum pressure capacity of 250 psig. Table 6 contains the results from the pipeline analysis when using PA as the pipe material.

Table 5: PA pipe sizes, length, and pressure table

Nominal Pipe size (in.)	Inner Diameter (in.)	Segment length (ft)	Pressure Capacity (psig)
2	1.917	1500	250
4	4.091	1500	250
6	6.023	500	250
8	7.841	50	250
12	11.591	50	250

Table 6: PA example pipeline results

Section	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psi)	Number of Compressors
A	6	3.21	500	53	67	0
B	4	3.48	1500	4	25	0
C	8	2.84	50	1373	102	0
D	6	2.68	500	106	97	0
E	12	2.02	50	6336	161	0
F	8	1.26	50	5280	92	0
G	6	1.07	500	423	76	0
TOTAL				13575		0

Epoxy Resin

The epoxy resin pipe considered in this study is Red Thread II. It has been utilized in gasoline pumping stations and in various harsh chemical gathering installations. The system relies on different joining techniques than that of the thermoplastic pipe materials but has a robust compliment of fittings and joints. The pipe is available in a wide variety of sizes but the OD's considered here range from 2 inches to 12 inches. This pipe is available in stick form only, and the pressure carrying capacity changes depending on the sizing of the pipe as shown in Table 7. Table 8 contains the results from the pipeline analysis when using Red Thread II as the pipe material.

Table 7: Red Thread II pipe sizes, length, and pressure table

Red Thread Pipe Sizes (in.)	Inner Diameter (in.)	Segment Length (ft.)	Pressure Capacity (psig)
2	2.238	30	450
3	3.363	30	450
4	4.364	30	450
6	6.408	30	450
8	8.356	40	225
10	10.357	40	225
12	12.278	40	225

Table 8: Red Thread II example pipeline results

Section	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psi)	Number of Compressors
A	4	6.12	30	880	318	0
B	3	5.15	30	176	64	0
C	6	4.26	30	2288	271	0
D	6	2.37	30	1760	72	0
E	12	1.80	40	7920	123	0
F	6	1.89	30	8800	243	0
G	4	2.04	30	7040	354	0
TOTAL				28864		0

Composite Pipe

The composite pipe considered here is Flexpipe in two different pressure carrying capacities. This material was chosen for its proven use in oil gathering systems, and has been used with ethanol on a small scale in the past. The composite pipe has a high pressure carrying capacity up to 1,500 psig. The currently available sizes are 2, 3, and 4 inches OD pipes. They are all able to be spooled up to a maximum length, as shown in Table 9. Table 10 contains the results from the pipeline analysis when using Flexpipe as the pipe material. Section E with its high required volumetric flow rate, led to a system pressure that is too high for the small diameter Flexpipe to accommodate. To reduce this pressure multiple pumping stations would be necessary to allow for a lower operating pressure. However, depending on the economical analysis, it could be more prudent to add a second pipe for that section. If this was done, the fluid flow per pipe would be halved and the number of necessary compressor stations would be reduced to 5 for each pipe.

Table 9: Flexpipe sizes, length, and pressure table

Product	Nominal Pipe Size (in.)	Inner Diameter (in.)	Segment Length (ft.)	Pressure Capacity (psig)
FP601	2	2.12	3281	1500
FP601	3	3.02	2297	1500
FP601	4	3.90	1968	1500
FP301	2	2.12	6562	750
FP301	3	3.02	4921	750
FP301	4	3.90	2491	750

Table 10: Flexpipe example pipeline results

Section	Pipe Product	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psi)	Number of Compressors
A	FP301	4	7.67	2491	11	538	0
B	FP301	3	6.39	4921	2	106	0
C	FP601	4	11.50	1968	35	2915	1
D	FP601	4	6.39	1968	27	776	0
E	FP601	4	17.89	1968	161	30038	20
F	FP601	4	5.11	1968	135	2595	1
G	FP301	4	2.56	2491	85	601	0
TOTAL					456		22

Long Term Performance Considerations

Thermoplastic Pipe (HDPE and PA)

The thermoplastic piping systems described here have been used in piping systems for extended periods of time. At the operating temperature and pressures expected for this type of pipeline there is not a concern for premature failure. Thermoplastic pipes have a shorter life expectancy when exposed to higher field temperatures and pressures. However, this is taken into consideration with the design factor and HDB calculations that assume an operating temperature of 73 °F. Other factors, such as installation procedures, can reduce the life expectancy of a pipeline. There are standards and accepted procedures that, if followed, significantly reduce the risks from other mitigating factors such as a poorly installed joint or rocky back fill.

The expectant long term strength and lifetime of the thermo plastic pipe could be affected by the presence of ethanol and its constituents. There was little to no data demonstrating the effects that ethanol had on these materials in a stressed and flowing state. Further study would be necessary to verify the long term performance of these materials when transporting ethanol.

Epoxy Resin Pipe

The Red Thread II pipe considered here has an extensive case history of use in different gathering environments. Proper installation and joining procedures is important to maintaining the life expectancy of a piping system. The expectant long term strength and lifetime of the epoxy resin pipe could be affected by the presence of ethanol and its constituents, though looking at the case history of the product and similar products ethanol does not appear to have an adverse effect on the pipe material. This cannot be confirmed, as there was no direct testing performed with ethanol as the test fluid to determine any negative effects. Further study and standardized ethanol testing would be advisable to verify the long term performance of these materials.

Composite Pipe

Flexpipe, the composite pipe considered in this case study can have different thermoplastic materials as the inner layer of the pipe as the barrier layer. The remaining composite layers provide the pressure carrying capacity. These systems have been used in gathering system and within a plant to transport methanol and ethanol. Proper installation and joining procedures are important to maintaining the life expectancy of a piping system. In the case of composite pipe extra care to prevent cyclic loading from pumping stations is necessary. This can be achieved by utilizing centrifugal pumping stations and/or reducing the pressure rating of the pipe if a consistent pressure cannot be maintained. However, there was no direct testing performed with ethanol as the test fluid to determine negative effects. Further study and standardized ethanol testing would be necessary to verify the long term performance of these pipe materials.

Test Case Summary

Additional material testing is recommended to demonstrate little to no negative effects from ethanol on these pipe materials. If these materials do not have degradation from the pressurized ethanol, than each of these pipe materials could transport ethanol effectively. All of the pipe systems discussed here have a variety of fittings and transitions to make connections as necessary. Each system would need further engineering considerations for crossings, pumping stations, and the most appropriate installation method.

Technical Status / Results – Economic Analysis (Task 5)

Introduction

The pipe system economic evaluation is based on a value engineering methodology, or maximum performance level at minimum cost, which incorporates and considers several components. These include:

- Material compatibility and performance,
- Pipe (resin and extruding costs if appropriate), fitting, and other appropriate material costs,
- Installed costs under a specific set of parameters, and
- Maintenance costs over the life of the installations when available.

The previously completed task work of this project focused on the material compatibility and performance in gathering and transporting ethanol and ethanol blends (Task 3). Several materials were identified as potential candidates, and those were further evaluated for operational effectiveness in Task 4. A theoretical ethanol gathering pipeline scenario (Figure 1) was developed to facilitate benchmarking of pipe system operational performance and included parameters such as flow rate, pipe size, pipe performance characteristics, and ethanol properties to calculate flow regimes for each potential pipeline material candidate.

Pipeline material candidates selected for operational evaluation were:

- High Density Polyethylene (HDPE)
- Polyamides (PA12)
- Epoxy Resin Pipe (Red Thread II)
- Composite Pipe (Flexpipe)

These systems are further explored for economic viability within this section. This presents a difficult task, as raw material costs, such as resins and steel, are constantly changing over time and can have significant variability. This variability makes it impractical to perform a long term evaluation of pipeline system costs, and subsequently any monetary calculations within this analysis should be considered a “snap-shot in time” and periodically updated. To account for this variability in material pricing, a dynamic economical model was developed to provide the base requirements with price as the only variable input. The economic model is based on the theoretical ethanol gathering pipeline system referenced earlier in this report. This is described in more detail below.

While the installed cost of the pipe systems is critical to the decision of which material to use, it also depends on many factors. These include:

- geographic location of the installation (soil type/conditions),
- paved or non-paved locations,
- length of the pipeline,
- diameter of the pipe,
- form of installation (coiled PE or sticks) number of valves and fittings to be installed,
- joining methods, and
- Special requirements such as: pipe supports, coatings, or insulation requirements.

Particularly on newer material (Red Thread II, Flexpipe) and specifically larger diameter systems, this information can be difficult to attain given its current applications are generally outside ethanol pipeline transportation and have had limited installation on this scale.

Maintenance costs must also be considered as carbon steel pipe will be used as a comparative baseline for the analysis, and may vary significantly from thermoplastic materials with the requirement of long term cathodic protection (buried pipe).

Economic Analysis

As referenced in the introduction, a theoretical ethanol gathering system was developed to both identify operating parameters and performance as well as provide a foundation for economic analysis of the selected piping systems. The structure of the model is designed to allow the user to create multiple operating scenarios for each piping system with the goal of developing the most economical solution, minimizing cost through effective selection of pipe diameter (material cost) and required pipeline compression. Operational parameters of the theoretical system are described in the detail for calculation of pressure differentials for the

selected material across the system. General variables in the pricing component of the system include:

- Pipe Material
- Pipe Diameter
- Pipe Length
- Cost Per Foot
- Install Cost per Foot
- Cost per joint fitting
- Cost of compression

Though a simple model, it provides a basis for system economic comparisons relative to each other as well as general pricing for individual systems. The model does not take into consideration installation situations created by geographical or environmental challenges such as railroad and river crossings, permitting expenses, etc. It is assumed these expenses will be similar regardless of pipe material.

Material and installation costs have been challenging to acquire as all non-metallic materials with the exception of HDPE have relatively minimal field installations as a foundation for establishing price. Please note that information on these selected materials are still being acquired, and several materials and pipe sizes have no relevant or confirmed data available to GTI for reporting at this time. These values will be secured and a full economic analysis of each material based on the theoretical ethanol gathering system will be included in the final report of this project.

Test Case Economic Scenario

To ensure a relative economic comparison and minimize operational related cost variability, a basic set of parameters will be used to perform a test case cost scenario. To this purpose, a single gathering line (Terminal 2, Segment B from Figure 1) was selected. Given the amount of cost information available for selected materials, the test case scenario will include Carbon Steel, HDPE, and PA12 in 4" diameter pipe. The segment and operating parameters are defined in Table 11. In a field installed scenario, 4" pipe diameter may not necessarily be the optimal selection given the operational parameters, however does simplify the test case scenario by eliminating the need for compression as well as utilize cost information available at the time of this report.

Table 11. Baseline Operating Parameters – Segment B

Pipe Diameter	Flow Requirement	Operating Pressure	Pipeline Length
4"	75 mGal/yr	Minimum 20 psig	~ 1 mile (~5,300 linear ft)

Pipe designation, specifications, material costs, installed costs, and potential maintenance costs are summarized in Table 12 for those materials with verified relevant information available at the time of submitting this quarterly report. Systems included for theoretical gathering system modeling are listed first, with subsequent materials identified as compatible with ethanol and with cost information available also included.

Table 12. Material Cost Summary

Material	Material	Material Cost (\$/ft)	Installed Cost/ft	Maintenance Cost
Carbon Steel	API5L-X42 STD Wall, DRL, ERW, FBE Coated, Domestic	Direct Quote (9/2009) - \$6.95 6 month Range: \$6.95 - \$10.86 ⁽¹⁾⁽⁵⁾	\$16 - \$32 ⁽¹⁾ \$18 - \$59 ⁽²⁾	\$3,500 - \$4000/mile install costs ⁽³⁾ \$300 - \$455/mile/year maintenance costs (average) ⁽²⁾
HDPE	4710 and 3708	Direct Quote (9/2009) - \$1.85 6 month Range: \$1.85 - \$3.70 ⁽⁴⁾	\$8 - \$16 ⁽¹⁾	N/A
Polyamide	Nylon, PA 11	Estimated Range at \$12 - \$15 ⁽⁴⁾	\$8 - \$16 ⁽¹⁾⁽⁵⁾	N/A
Polyamide	Nylon, PA 12	Estimated Range at \$9 - \$12 ⁽⁴⁾	\$8 - \$16 ⁽¹⁾⁽⁵⁾	N/A
Epoxy Resin	Red Thread II	Not Available	Not Available	N/A
Composite	Flexpipe FP301	Not Available	Not Available	N/A
PVDF	2020, 2025	Estimated Range \$18 - \$24 ⁽⁴⁾	Not Available	N/A
PA 12 w/PVDF Layer	Nylon, PA 12 2020, 2025 PVDF	Estimated Range at \$11 - \$14 ⁽⁴⁾	Not Available	N/A
PEX	Cross-linked PE 008, 1008	Estimated Range at \$4 - \$6 ⁽⁴⁾ Price Quote of 1" PEX - \$2.35	Not Available	N/A

(1) Tubbs, 43rd Annual Pipe Report – “Gas Demand, Maintenance Projected to Drive Distribution Spending”, Pipeline Gas Journal, December 2008.

(2) Atofina Chemicals, Inc, “Evaluation of Market Potential for PA11, An Executive Summary”, May 2002.

(3) Cynergy Corp, Gas Engineering Department, “Evaluation of 12” Polyethylene Pipe for Cynergy Gas Distribution”. March 2004.

(4) Based on information and discussions with multiple sources including Arkema, Evonik Degussa, Performance Pipe Institute, UBE America, Energy West Inc., Nicor Gas Inc., Groebner & Associates and Resource Center for Energy Economics and Regulation.

(5) For the purpose of this example scenario, it is assumed installation costs for PA11 and PA12 will be similar to that of HDPE for 4” pipe. This is based on each material being available in coils and butt fusion utilized for joining segments of pipe.

Given the operating parameters outlined for the test case scenario, flow calculations were applied and the economic results were calculated for the 3 materials identified. These results are summarized in Table 13 and Table 14.

Table 13: Test Case Scenario (Section B) Operating Parameters

Pipe Product	Section	Flow (gal/min)	Min. Recommended Pipe Size	Pipe Size (Inch)	Flow Rate (ft/sec)	Total Length(miles)	PipeSection length (ft)	Number of Joints	Equivalent Length (feet)	Pressure Drop (psi)	Min Pressure (psi)	Max Pipe Pressure	Number of Compressors
PA12	B	143	2.71	4	3.48	1	1500	4	5336	25	20	250	0
HDPE	B	143	2.71	4	3.48	1	1500	4	5323	25	20	125	0
X42 Steel	B	143	2.71	4	3.48	1	40	132	5280	25	20	300+	0

Table 14: Test Case Scenario (Section B) Cost Results

Pipe Product	Section	Cost Of Material	Cost of Install	Total Cost
PA12	B	\$55,440⁽¹⁾	\$63,360 ⁽²⁾	\$118,800
HDPE	B	\$9,768⁽³⁾	\$63,360⁽⁴⁾	\$73,128
X42 Steel	B	\$36,696⁽⁵⁾	\$158,400⁽⁶⁾	\$195,096

(1) Average price of \$10.50 used in calculation

(2) Average price of \$12 used in calculation

(3) Direct quote price of \$1.85 used in calculation

(4) Average price of \$12 used in calculation

(5) Direct quote price of \$6.95 used in calculation

(6) Average price of \$30 used in calculation

As mentioned above, assumptions are inherently incorporated into the calculations and a simplified test case scenario generated to illustrate the ability of the model to develop economic scenarios. Also not included in the table above is additional annual maintenance costs associated with carbon steel pipelines. This can be as high as several thousand dollars annually per mile of pipeline. The flow and economic calculator will be refined and made available to DOT PHMSA with the final report.

Plans for Future Activity

- Prepare the final report for DOT PHMSA review.

Respectfully Submitted,

Andy Hammerschmidt & Daniel Ersoy, GTI

End of Report